SMALL - SCALE MORPHOLOGY AND BOUNDARY LAYER PROCESSES: MEASUREMENT AND MODELING

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LONG-TERM GOALS

The main goal of the research project is to contribute to a better understanding of the basic mechanisms controlling sediment transport in the nearshore regions. In particular the structure of flow in the bottom boundary layer is of interest along with its interaction with sediment dynamics.

OBJECTIVES

We want to look at the dynamics of the coherent vortex structures which are generated at the bottom of sea waves by 1) the instability of the laminar boundary layer 2) the nonlinear interaction of the oscillatory boundary layer with a wavy bed 3) The separation of the boundary layer at the crests of 2-D ripples of large amplitude. The flow will then be used to study sediment dynamics.

APPROACH

The investigation is mainly based on numerical simulations of momentum (Navier-Stokes) and continuity equations. The codes consider the full 3-D problem and are mainly based on a time-splitting procedure where momentum equations are used to explicitly advance the flow in time and continuity is forced by solving a Poisson equation for pressure.
Because of the simplifying assumptions, which unavoidably are introduced in numerical modeling, field data are used to test the numerical findings.

WORK COMPLETED

a) The code to study transition from the laminar to the turbulent regime in the boundary layer at the bottom of sea waves (sketchy at the beginning of the project) has been completed and tested. Moreover preliminary results have been obtained.

b) The code to study the separated oscillatory flow close to a rippled sea bed has been written. Preliminary tests seem to indicate that only moderate values of the Reynolds number can be handled.

Report Documentation Page

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1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Small - Scale Morphology and Boundary Layer Processes: Measurement and Modeling**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Oceanography,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

c) Wave boundary layer processes and small-scale morphology were measured during the SandyDuck experiment with instrumentation mounted on a moveable sled. A unique Bistatic Acoustic Doppler Velocimeter (BCDV) measured the wave boundary layer by simultaneously obtaining 3 components of velocity every 5 cm over the bottom 90 at a 48 Hz sampling rate. The suspended sediments, measured as a function of the blackscatter intensity, and the vertical velocity were measured every 1.6 cm over the bottom 90 cm. It was essential the small-scale morphology be well resolved at the same time. The morphology was measured with a new rotating sonar system which resolved the morphology every 2 cm horizontally and 1 cm in the vertical over a 3m x 3m square directly beneath the BCDV. The cross-shore coherence length scale of the suspended sediment was also measured with an array of 6 optical blackscatter instruments. Cross-shore transects of the boundary layer process at 8-14 locations starting well outside the surf zone in about 4 m depth were obtained at least daily. The data are being analyzed and compared with models.

d) The theoretical investigation of the interaction between Stokes' drift and ripple development (almost finished at the beginning of the project) has been completed and results have been obtained.

e) The cooperation between the Naval Postgraduate School and Genoa University has been started and in particular Prof. Blondeaux and Dr. Vittori have visited N.P.S. and have given two seminars on ripple formation and development and on edge wave excitation by random waves.

Moreover NICOP is paying the expenses of Professor Enrico Foti, Catania University, Italy to collaborate with Professor Ed Thornton at the Naval Postgraduate School for six months between August 1997 to January 1998. During his stay he partecipated in the SandyDuck nearshore experiment at Duck, North Carolina during the months of September and October 1997. His participation in the field experiment has enhanced his appreciation for the modeling of natural bottom boundary layer processes.

RESULTS

On the basis of direct simulations of an oscillatory flow close to a flat but imperfect wall, it has been possible to delineate the mechanism of transition from the laminar to the intermittently turbulent regime through the disturbed laminar regime in a Stokes boundary layer. In the disturbed laminar regime it has been shown that the disturbances observed in experiments are induced by imperfections of the bottom which in turn excite the modes known to be momentarily unstable on the basis of a momentary stability analysis. The flow field in the disturbed laminar regime turns out to be highly two-dimensional and periodic. As R_d exceeds 550 three-dimensional components appear and the 'intermittently turbulent regime' is found. Moreover it has been observed that the value of the time averaged vertically integrated specific kinetic energy of the disturbances E depends both on the Reynolds number R_d and on the amplitude ε of the wall imperfections in the 'disturbed laminar' regime, while in the 'intermittently turbulent' regime E is found to be independent of ε and to depend only weakly on R_d. The runs for Reynolds number in the intermittently turbulent regime have allowed to investigate the characteristics of turbulence. In particular the analysis of the temporal development of the different terms of the turbulent kinetic energy equation, has shown that equilibrium conditions are never strictly attained. Indeed while the accelerating part of the cycle is characterized by turbulent production, dissipation starts to

grow during the decelerating phase. Therefore 'quasi equilibrium' conditions are observed only during a small part of the decelerating phase.

Ripple formation under sea waves has been investigated by means of linear and weakly nonlinear stability analyses of a flat sandy bottom subject to the viscous flow which is present in the boundary layer at the bottom of propagating sea waves. Nonlinear terms in momentum equation have been retained to account for the presence of a steady drift. The analysis assumes the flow regime in the bottom boundary layer to be laminar and the results are significant for ripples at the initial stage of their formation or for mature ripples of small amplitude (rolling-grain ripples) For these reasons the work (a) and (b) has been undertaken. It has been found that the presence of a steady drift has neither stabilizing nor destabilizing effects on the process of ripple formation. Hence the results described in Blondeaux (1990), concerning the critical values of the sediment Froude number F_d and ripple wave number are not changed. The obtained results indicate that the growth of bottom perturbations takes place simultaneously with their migration in the onshore direction. In fact the imaginary part of the amplification rate G_1 turns out to be positive whatever value of a is considered thus indicating that the steady drift at the bottom of sea waves tends to drag the ripples which therefore migrate in the onshore direction. Of course larger values of Re imply stronger steady currents and hence larger migration speed. Even though for small values of the sediment Reynolds number R_d the theory tends to underestimate the migration speed of ripples while for large values of R_d it tends to overestimate it, the trend of the experimental data is well predicted by the analysis and the quantitative agreement between the theoretical predictions and the experimental findings is fair, taking into account the uncertainty in the sediment transport rate formulae.

RELATED PROJECTS

- "Sediment Transport Modeling in Marine Coastal Environments" research project of European Union. MAST III, No PL 961115.
- "Prediction of aggregated-scale coastal evolution" research project of European Union. MAST III, No PL 950021

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